UNIVERSITY OF MICHIGAN

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Curb Space Management for Multi-Modal Transportation in Downtown Areas

Madison Carlson
Xin Dong
Arya Pudota
Xiaotong Sun
Jun Ying

Supervised by
Dr. Neda Masoud

In collaboration with
City of Ann Arbor

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List of Acronyms

City of AA City of Ann Arbor

DDA The Ann Arbor Downtown Development Authority

RPS Republic Parking System Company

TheRide The Ann Arbor Area Transportation Authority

MDOT Michigan Department of Transportation

1 Overview

This document is prepared for the '2020 Transportation Technology Tournament' hosted by the National Operations Center of Excellence and the U.S. DOT ITS JOP PCB program. This document presents a suite of solutions for curb space management in downtown areas, a problem posed to the team by the city of Ann Arbor. The University of Michigan Team has summarized the current situation of the Ann Arbor downtown area, analyzed a number of potential solutions, identified the final recommended solutions, tackling the problem from both the supply and demand perspectives. The first section will summarize the study scope, identify the problem, and introduce some details. This includes the study area, current situation and considerations of stakeholders. The second section will list a number of solutions that strive to improve curb space usage by focusing on the supply of curb space, hereafter referred to as "supply-focused" solutions, a number of solutions that attempt to shift the need for curb space use, hereafter referred to as "demand-focused" solutions, and their corresponding con-ops based on existing ITS service packages. Also the estimated cost breakdown and timeline will be visualized. Section 3 will discuss several anticipated impacts, challenges and outcomes, considering the operational benefits, mobility improvements, safety improvements, environmental benefits, and economic benefits of the proposed solutions. The solution we proposed could be summarized as followed:

- Supply-focused: Design a seasonally- and hourly-dynamical allocation of curb space, and take advantage of flexible-use zoning. Enhance the infrastructure to serve multi-modal transportation solutions, such as digital curb space information boards, infrastructure-based navigation systems, and scooter parking spaces, etc.
- Demand-focused: Use dynamic pricing to balance the supply and demand of on-street parking. Build an integrated transportation-information system to promote communication between multiple stakeholders. Release smart phone apps to public that could guide vehicles to park in locations with more parking availability to reduce downtown congestion, and guarantee the convenience of travelling the last mile from parking to their final destination.

1.1 Problem Statement

Curb space management is fundamentally about how to devise schemes that can improve mobility and safety for various stakeholders by optimizing curb space allocation. Curb space management has gone through the history of realizing a usage equity among customer parking, residential parking and freight loading since the beginning of the 20^{th} century. With the boom of the economy, the retail corridors have larger demand for on-street parking spaces, but the dense urban cores have only scarce curb space resources. Additionally, the prevalence of ridesourcing companies in recent years had added to the demand for curb space usage. Many cities have tried time-limits and pricing schemes to balance supply and demand of customer parking and to promote turn-overs since 1940s. For on-street parking in residential areas, many cities have launched a residential parking permit program to protect the priority of residents' access from commuters' and customers' intrusion since 1980s. At the beginning, the relatively low nominal annual fee led to the situation that permits often outnumbered parking supply, leading to evolving policies that redefined residence zones and reducing number of permits, revision upon revision. Almost during the same time period, pricing, location , and time limits of loading zone were starting to be discussed. From the beginning of the 21^{st} century, with the rise of new modes of mobility, such as scooters, ride-sharing, car-pooling and ridesourcing , curb space has become the battle ground for multi-modal mobility.

To satisfy the original needs for curb spaces, such as on-street parking and loading zones, supply-demand balance needs to be analyzed, and corresponding management plans should be updated. The curb spaces for new modes of mobility should also be considered. Based on these two considerations, we analyzed the current curb space management situation in downtown Ann Arbor and proposed our solutions that focus on the supply and demand sides. Such solutions require rethinking of curb space allocation and management in an integrated way.

1.2 Study Area

Ann Arbor is a mid-size city with a population of about 115,000 residents, making it the fifth largest city in the state of Michigan. In 2017, Transportation for America (T4A) launched the Smart Cities Collaborative in several leading-edge cities to advance smart mobility policies and projects. For this initiative, three cities were chosen as"pilot cities" and thirteen cities as "peer citie", with diversity in size, geography, income, and jurisdiction [1]. Ann Arbor was selected as one of the peer cities, as downtown Ann Arbor was identified as a congested area that needs to be re-organized through both short- and a long-term transportation planning. Ann Arbor is also an interesting city to study as the housing prices in Ann Arbor are higher than its neighboring cities, prompting people to leave outside of Ann Arbor and commute to work. As such, about 80% of the Ann Arbor work force migrates from outside of the city, contributing to congestion. These attributes make curb space a highly sought-after resource in downtown Ann Arbor. Our study goal is to provide a suite of tools and solutions to promote informed and targeted curb space management strategies in downtown and commercial areas in Ann Arbor. The study area is the area circled in dash line in Figure 1.

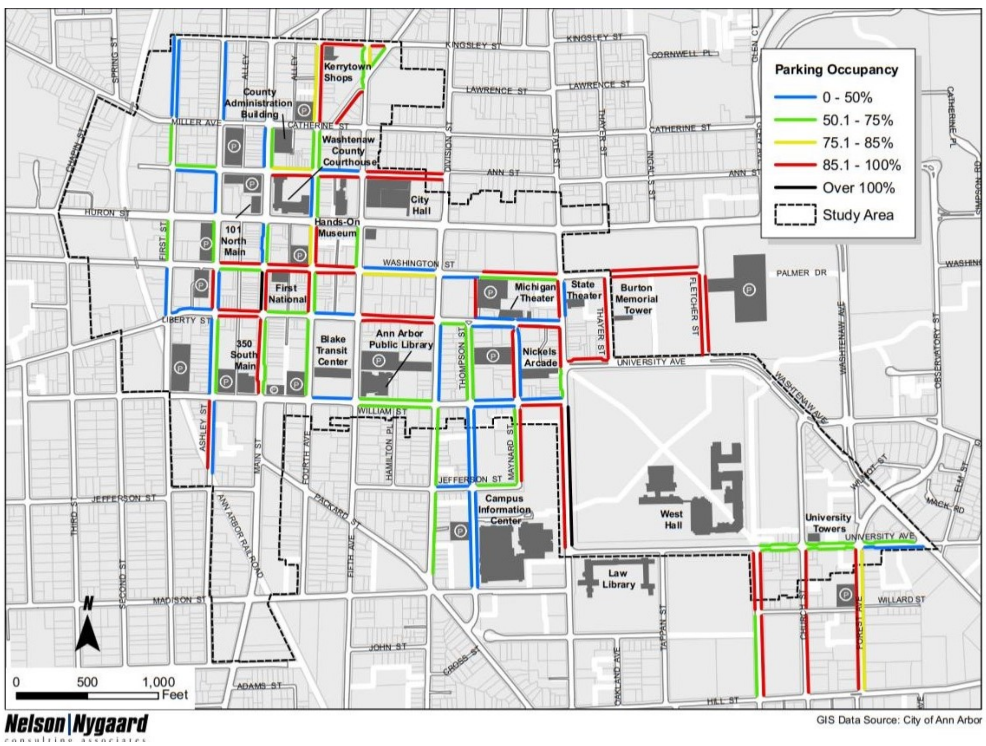

Figure 1: Study Area: Ann Arbor Downtown

1.3 Current Situation

Based on our observation, currently the curb space is mostly used for parking or biking-parking shared lane. According to the website of Republic Parking System (RPS) [2], which is hired by the City of Ann Arbor to manage city parking, RPS manages 1063 on-street spaces and 4707 off-street spaces in Ann Arbor, totaling 5770 spaces in the downtown area. Ann Arbor downtown parking report in 2006 [3] (the most recent report) shows that on-street parking spots are highly occupied by customers who need to have a quick access to businesses during night time (6pm-9pm). During weekdays, some commuters use the residential parking and on-street parking meters according to a survey conduced by getDowntown organization [4]. The report also shows that the higher the time limits for parking, the higher occupancy rate, which shows the current on-street parking needs to improve its turn-over rate.

Curb space has traditionally been a critical resource for transit vehicles, business (both customers and loading/unloading), parking, and biking. However, the advent of new shared mobility platforms has risen the demand for this scarce resource even higher. Due to scarcity of parking in downtown Ann Arbor, ridesourcing companies like Uber and Lyft visit the down town area often, making temporary parking an even more valuable commodity. On one hand, without access to temporary parking, ridesourcing vehicles resort to cruising while waiting for their next assignment, which contributes to the already heavy congestion in downtown Ann Arbor. On the other hand, allocating parking to these vehicles will exacerbate the parking shortage. Other shared mobility services, such as bike-, car-, and scooter-sharing, are also in need of curb space for their operation. In 2019, the city council and the University of Michigan approved an agreement with Spin, Inc. to operate spin in Ann Arbor [5].

1.4 Existing Management

The Downtown Development Authority (DDA) Act was passed by the State of Michigan in 1975 to give municipalities an economic development tool to rebuild and re-position their downtown, increase taxable values and encourage private investment [6]. Based on this act, the City of Ann Arbor oversees management of all public parking structures, lots, and meters. Ann Arbor DDA uses the services offered by the parking management company Republic Parking System to meet the city's parking needs, by making available the epark app for on-street parking meters to public in order to promote online payment through smart phones.

2 Solution Statement

The utilization of curb space, similar to any other commodity, occurs at the equilibrium point where supply and demand curves meet. The equilibrium in any economic market is the result of the interplay of supply and demand. Therefore, solutions designed to change the equilibrium could target the supply side, the demand side, or both. Therefore, we identify two sets of solutions to change people's use of curb space in downtown Ann Arbor. We distinguish the solutions by whether they shift the supply of curb space or the demand for curb space usage in downtown Ann Arbor.

2.1 Supply-Focused Solutions

2.1.1 solution

With the growing diversity of transportation modes, demand for curb space is changing constantly. As such, supply should be modified dynamically to satisfy people's needs. A number of cities around the world have conducted pilot projects to address this need. For example, Barcelona allocates curb space to normal traffic, bicycle travel, bus use and night-time parking according to time of day and day of week [7]. As another example, the city of Copenhagen divides the curb space into different zones, alternatively allowing different transportation modes to use the curb space at different times of the day [7]. Inspired by these trials, we think a tailored flexible curb space management method is worth investigating in Ann Arbor.

2.1.1.1 Analysis and Description

The Ann Arbor downtown parking report in 2006 [3] shows the on-street parking occupancy is 68% for weekdays and 98% for weeknights, and 100% for Friday nights. This report shows that the off-street occupancy is 84% for weekdays, 35% for weeknights and 48% on Friday nights. Therefore for on-street parking, loading vehicles should be encouraged to load during the day, while during morning before the peak hour could be the most appropriate time. The report also provides a summary of on-street occupancy rates by time limits: the occupancy rate for parking spaces with 0.5-hour, 1-hour, and 2-hour limit are 50%, 62%, 75%, respectively. Allowing longer occupancy time would increase the parking vehicles, thus making it more difficult for the delivery and ridesourcing vehicles to find parking spaces for short time periods. This data also shows a low turn-over rate, Which is not in line with the main purpose of on-street parking. As such, vehicles with longer parking periods should be encouraged to park in vertical parking structures and save the curb spaces for other modes of mobility.

Reviewing this report indicates the need for a flexible curb space management to accommodate different uses at different time of day and season. We propose several solutions targeting the supply of curb space to regulate the efficient use curb spaces among different demand sources:

- **Using dynamic information boards to allocate different uses of curb spaces**
  Allocating more curb spaces to serve as loading zones in the morning and mid-night while allocating more spaces to pick-up and drop-off zones and delivery vehicles during night could lead to efficient use of curb space supply while at the same time satisfying different types of demand. Also considering the seasonal dependency of travelers' modal choice could give rise to seasonal allocation of curb spaces.

Such allocation can help utilizing curb spaces to the maximum. For example, bike lanes can open during summer time, while the curb space can be used for parking during winter time.

- **Providing substitution for on-street parking and saving spaces for other mobility modes**
  This solution focuses on developing other ways than on-street parking for providing access to popular locations. We can direct people to off-street parking by providing on-demand mobility options to cover the *last mile* of their trips. For example, in Ann Arbor,we can establish cooperation between under-utilized parking lots/structures in the down town area and the scooter sharing platform Spin Inc. to provide on-demand last-mile transporting, and reserve the curb space zones for ridesourcing companies and bike lanes. Such cooperation can improve the convenience of last-mile transporting from parking lot to stores, and increase accessibility to stores from off-street parking, and can reduce on-street parking demand.
- **Upgrading the infrastructure to support a smart parking system and a dynamic pricing system**
  This solution will use a smart phone application launched by municipal officials to efficiently guide vehicle to parking locations to reduce the unnecessary cruising and congestion in the downtown areas. This solution involves providing sensors and cameras for on-street parking spaces monitoring. It will also include starting a line of communication (through the app) between the smart parking system and drivers. By providing parking time limit information, pricing, and parking availability, the app could help reduce on-street parking. In addition to identifying empty spaces that will be shown in the app, the sensors can be used to feed information into dynamic pricing algorithms.

2.1.1.2 Con-ops

- Functional Architecture
  Some functions are included in this solution, such as TIC Data Collection, RSE Parking Management, etc. The physical, functional objects are selected from ITS service packages, and the architecture is visualized in Figure 1.
  graphicx

Physical Object	Functional Object	Description
Parking Management System	Parking Park and Ride Operations	Support park and ride operations, providing additional coordination with transit operations on parking arrivals and transit arrivals and departures, smoothing the transition between parking and riding.
Parking Management System	Parking Coordination	Support communication and coordination between equipped parking facilities and traffic management systems. Share information with transit management systems and information providers to support multimodal travel planning
Transportation Information Center	TIC Data Collection	Collect, analyze and refine transportation-related data, make it available to applications that support operational data sharing between centers, deliver traveler information to end-users. Share data with other transportation information center
Transportation Information Center	TIC Interactive Traveler Information	Disseminate personalized traveler information including traffic and road conditions, transit information, parking information, multimodal information, event information, and weather information.
Transportation Information Center	TIC Travel Services and Information and Reservation	Disseminate information about traveler services. Support reservations and advanced payment for traveler services including parking and loading zone use.
Transit Management Center	Transit Center Park and Ride Operations	Monitor park and ride customer arrivals in the parking facility and manage the transit services for those park and ride customers.
Vehicle OBE	Vehicle Basic Safety Communication	Exchange current vehicle location and motion with other vehicles, calculate vehicle paths and provide potential collision warning.
Vehicle OBE	Vehicle Interactive Traveler Information	Provide drivers with personalized traveler information including traffic and road conditions, transit information, multimodal information, event information, and weather information.
Vehicle OBE	Vehicle Roadside Information Reception	Receive advisories, vehicle signage data, and other driver information and present information to the driver using in-vehicle equipment.
Personal Information Device	Personal Interactive Traveler Information	Provide traffic and other traveler information that is specifically tailored based on the traveler's request and/or previously submitted traveler profile information.
Connected Vehicle Roadside Equipment	RSE Parking Management	Monitor the basic safety messages generated by connected vehicles to detect vehicles parking and maintain and report spaces that are occupied by connected vehicles.

Table 1: Functional Architecture of Supply-focused Solution

- Physical Architecture
  The physical architecture showed in Figure 2 explains how physical objects could cooperate with each other, and it is referred to ITS service package PM02 (The National ITS Reference Architecture), and we add some functions and information communication between Parking Management System and TIC.

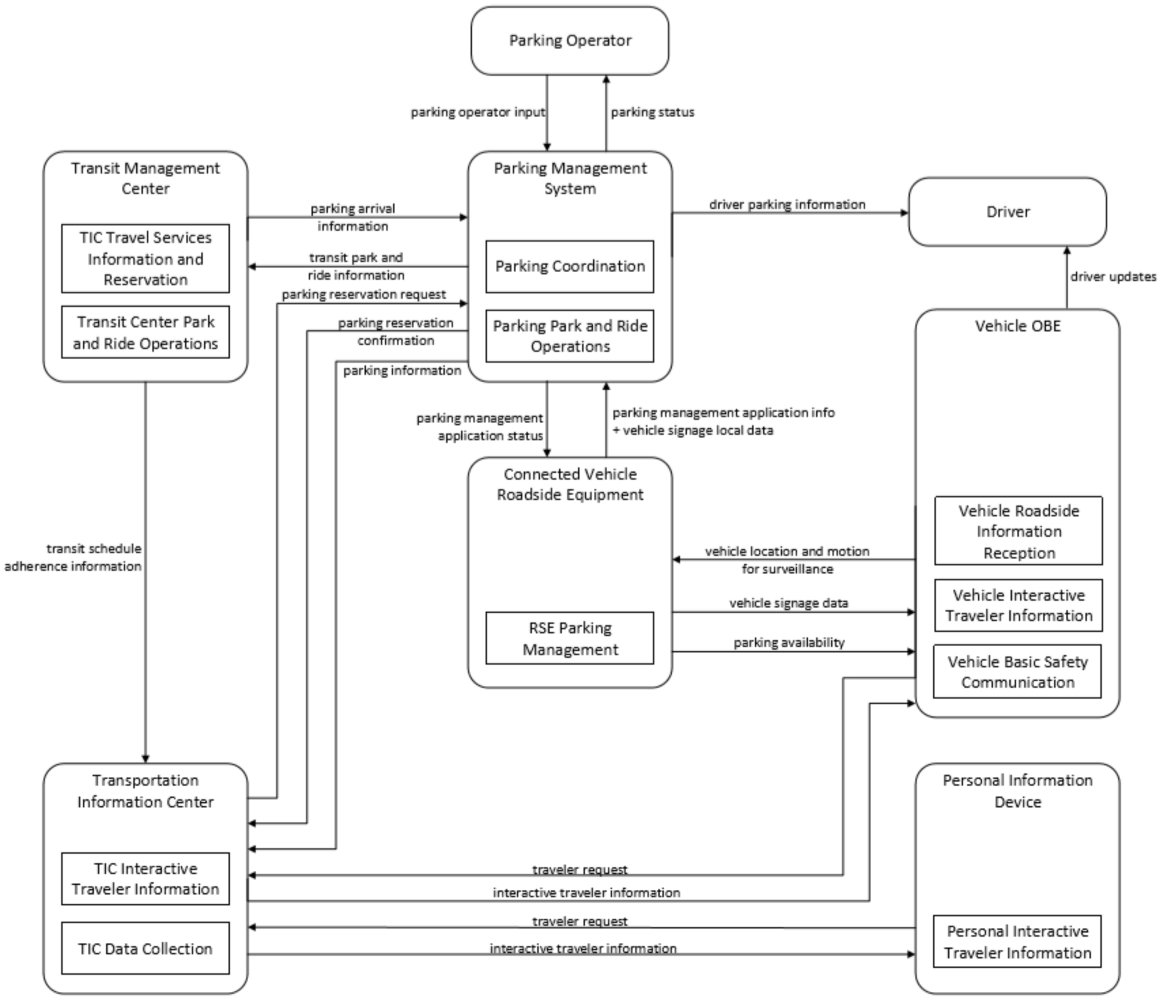

Figure 2: Physical Architecture of Supply-focused Solution

- Enterprise Architecture
  Physical objects and functional objects are also depicted as resources in the enterprise view, which describe the organizations that are involved, and the role they play. The enterprise architecture of the supply-focused solution is presented in Figure 3.

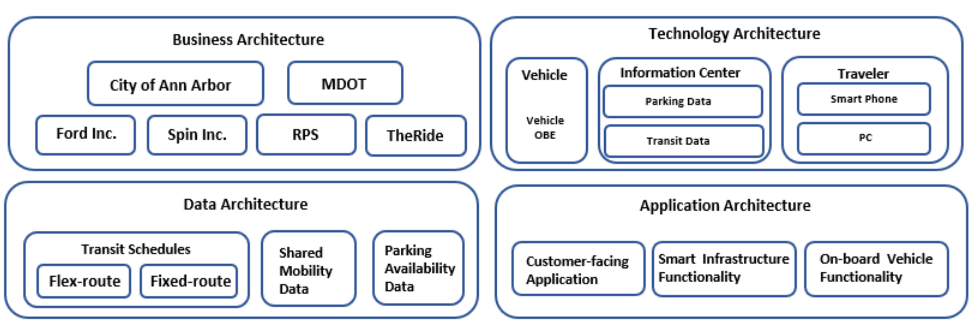

Figure 3: Enterprise Architecture for the Supply-focused Solution

- Cost Breakdown and Timeline
  Cost breakdown is shown in Table 2 sand timeline is shown in Table 3. Note that the high expense of

acquiring sensors in Table 2 could be to some extent alleviated by strategically placing cameras that can capture multiple spaces, and using video processing methods.

Table 2: Cost Breakdown of Supply-focused Solution

Description	Quantity	Unit Price	Subtotal
Roadside Signs	80	$ 30	$ 2,400
Smart Parking In-Ground Sensors in Parking Monitoring System	1063	$ 100	$ 106,300
Software for Traffic Information Dissemination	1	$ 18,000	$ 18,000
Scooters	200	$ 50	$ 10,000
			$ 136,700

Table 3: Timeline of Supply-focused Solution

Task	Time Estimation
Stakeholder Meetings	1 month
Public Hearing	3 months
Data Collection of Multi-function demands for On-street Parking	1 month
Flexible Zones Decisions	1 month
Infrastructure Construction	2 months
Trial Operation	2 months

2.2 Demand-Focused Solutions

2.2.1 Solution 1: Intelligent Curb Space Management

2.2.1.1 Analysis and Description

Having studied the dynamic pricing strategy in San Francisco, Seattle, Washington DC and New York (Table 4), we propose to adopt a pricing strategy based on a combination of zoning and land use, hours of day, real-time demand, and special events. (Zonal pricing means that the city is divided into contiguous meter rate zones. Variable pricing is a pricing method that varies on a street-by-street basis, and demand pricing means that meter rates are set to achieve occupancy target.)

Table 4: Summary Chart of Curb Space Management Policies

city	New York	San Francisco	Seattle	Washington DC	Ann Arbor
Max Pricing (per hour)	$6	$7	$5	$6	$1.9
Zonal Pricing	yes	yes	yes	yes	no
Variable Pricing	no	yes	yes	pilot	no
Demand pricing	pilot	yes	yes	pilot	no

Refer to the Ann Arbor Downtown Parking Report[3], downtown Ann Arbor was divided to four sub-areas: Main Street, Kerrytown, State Street, and South Campus, as shown in Figure 4. Based on this zone division, the report[3] also gives the statistics of on-street parking for different zones, as can be shown in Figure 4. It is easy to find the occupancy rate for different zones and for different time of day varies a lot. And according to report [8], the occupancy rate of on-street parking should be better to maintain around 85%, so pricing scheme could be applied to lower the demand. Price elasticity is an index that can help decide the pricing scheme. Parking price elasticity of demand is the responsiveness of demand for parking to a change of the price for parking, which can be defined in Equation 1. Pricing elasticity values for different cities and different parking types (off-street parking, on-street) varies. The value for Ann Arbor downtown can be inferred from next paragraph.

$$Parking \quad Price \quad Elasticity \quad = \quad \frac{Change \quad in \quad quantity \quad demand \quad (\%)}{Change \quad in \quad price \quad (\%)} \tag{1}$$

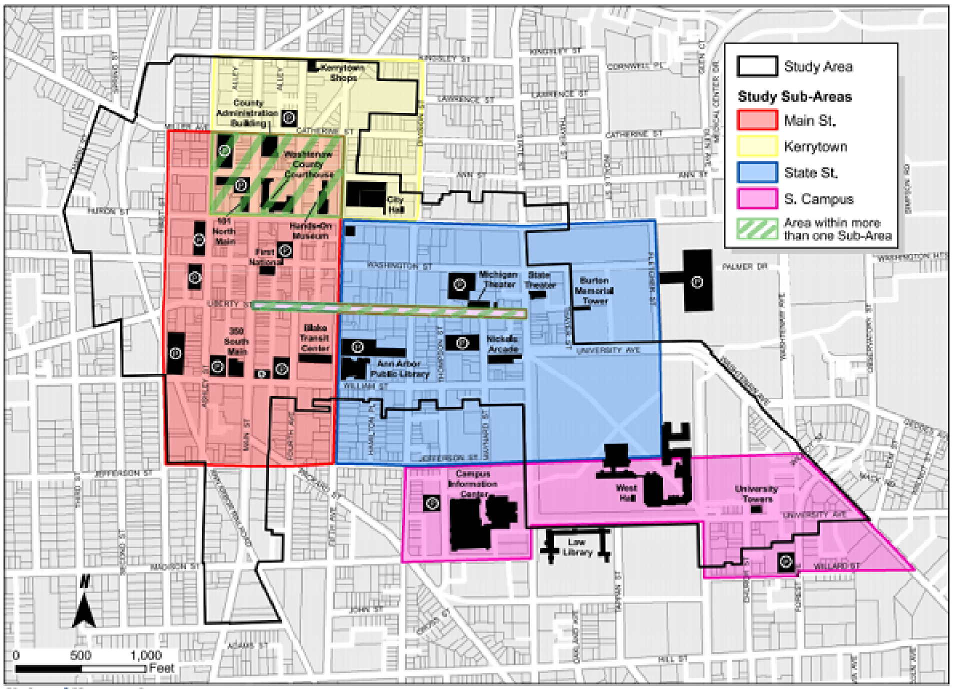

Figure 4: Parking Meter Locations

	Spaces			Weekday Occupancy			Evening Occupancy			Friday Night Occupancy		
Sub-Area	On Street	Off Street	Both	On Street	Off Street	Both	On Street	Off Street	Both	On Street	Off Street	Both
Main Street	345	2448	2793	68%	84%	82%	102%	38%	46%	109%	53%	60%
Kerrytown	175	1041	1216	74%	72%	73%	73%	43%	47%	81%	37%	43%
State Street	442	1517	1959	68%	82%	79%	107%	39%	54%	106%	50%	62%
South Campus	266	558	824	72%	100%	91%	98%	9%	38%	97%	17%	43%
All	1063	4707	5770	68%	84%	81%	98%	35%	47%	100%	48%	57%

Table 5: Parking Inventory Statistic by Sub-area

The study of San Francisco pricing parking by demand [9] shows that the on-street parking price elasticity of the downtown area is -0.43. Considering the difference of per capita income between San Francisco and Ann Arbor, people in Ann Arbor are more sensitive to price changing, so the absolute value of this index in Ann Arbor downtown should be higher. Besides, according to Yan et al.'s research [10] , the weighted parking price elasticity in Ann Arbor is -0.78, which is larger as the study focus mainly on the long-term commuting trips. Therefore, the on-street parking price elasticity of Ann Arbor should be a value between -0.43 and -0.78, more data and experiments are needed in order to obtain an exact value. For this study, we assume the on-street parking price elasticity as -0.6, thus based on the current pricing and on-street parking occupancy in Ann Arbor, the baseline for different areas and time period are set in Table 6.

Table 6: Downtown and Commercial Zone Meter Rate

Area/Time Period	8am-5pm	5pm-9pm
Main Street	$ 1.1	$ 2.4
Kerrytown	$ 1.4	$ 1.4
State Street	$ 1.1	$ 2.6
South Campus	$ 1.3	$ 2.3

Except for the differences among different zones, the occupancy for different streets within each zone changes a lot as well, as demonstrated in Figure 1. This difference in occupancy rate can be explained by the convenience of access to stores on specific streets. As such, to relive the over-whelming curb space demand on certain streets, we propose to implement dynamic pricing within zones to help balance the demand and supply for parking. Based on the metered rate, dynamic pricing rates can be adjusted using equations that can be obtained by studying supply an demand curves. Although developing the supply and demand curves could be labor extensive, requiring monitoring how public reacts to changes in curb space pricing and possibly conducting surveys, the resulting pricing rules can be easy to implement. An example of such rules, adopted from the dynamic pricing scheme in San Francisco, and adjusted based on Ann Arbor's per capita income, may include:

- When occupancy is 90 percent or above, the hourly rate is raised by $0.15.
- When occupancy is between 80 percent and 90 percent, the hourly rate is not changed.
- When occupancy is below 80 percent, the hourly rate is reduced by $0.15.

Roadside loop detectors and video cameras could be applied to monitor the real time parking occupancy, and assist with adjusting the metered rates dynamically.

2.2.1.2 Con-ops

- Functional Architecture

Physical Object	Functional Object	Description
Payment Administration Center	PAC Payment Administration	Provide administration and management of payments associated with electronic toll collection, parking payments, and other e-payments. Support dynamic pricing to support demand management
Parking Management System	Parking Electronic Payment	Support electronic payment of parking fees using in-vehicle equipment (e.g., tags) or contact or proximity cards.
Personal Information Device	Personal Interactive Traveler Information	Provide traffic information, road conditions, transit information, yellow pages (traveler services) information, special event information, and other traveler information. Support interactive services that support enrollment, account management, and payment.
Connected Vehicle Roadside Equipment	RSE Parking Management	Monitor, maintain and report spaces that are occupied by connected vehicles. Provide parking information to vehicles in need.
Connected Vehicle Roadside Equipment	RSE Payment Support	It requests, receives, processes, and reports vehicle payment information.
Vehicle OBE	Vehicle Basic Toll/Parking Payment	It includes the 'tag' in-vehicle equipment that communicates with the toll/parking plaza and an optional interface to a carry-in payment device.
Vehicle OBE	Vehicle Payment Service	To support VMT-based payment, this application tracks the location of the vehicle at specific times and reports this VMT data along with vehicle identification. A variety of pricing strategies are supported, including strategies that include credits or incentives that reward desired driving patterns and behavior.

Table 7: Functional Architecture for the Demand-focused Solution 1

- Physical Architecture
  The physical architecture of the demand-focused solution one showed in Figure 5 is referred to ITS service package PM03 (The National ITS Reference Architecture).
- Enterprise Architecture
  The enterprise architecture of the demand-focused solution one is presented in Figure 6.

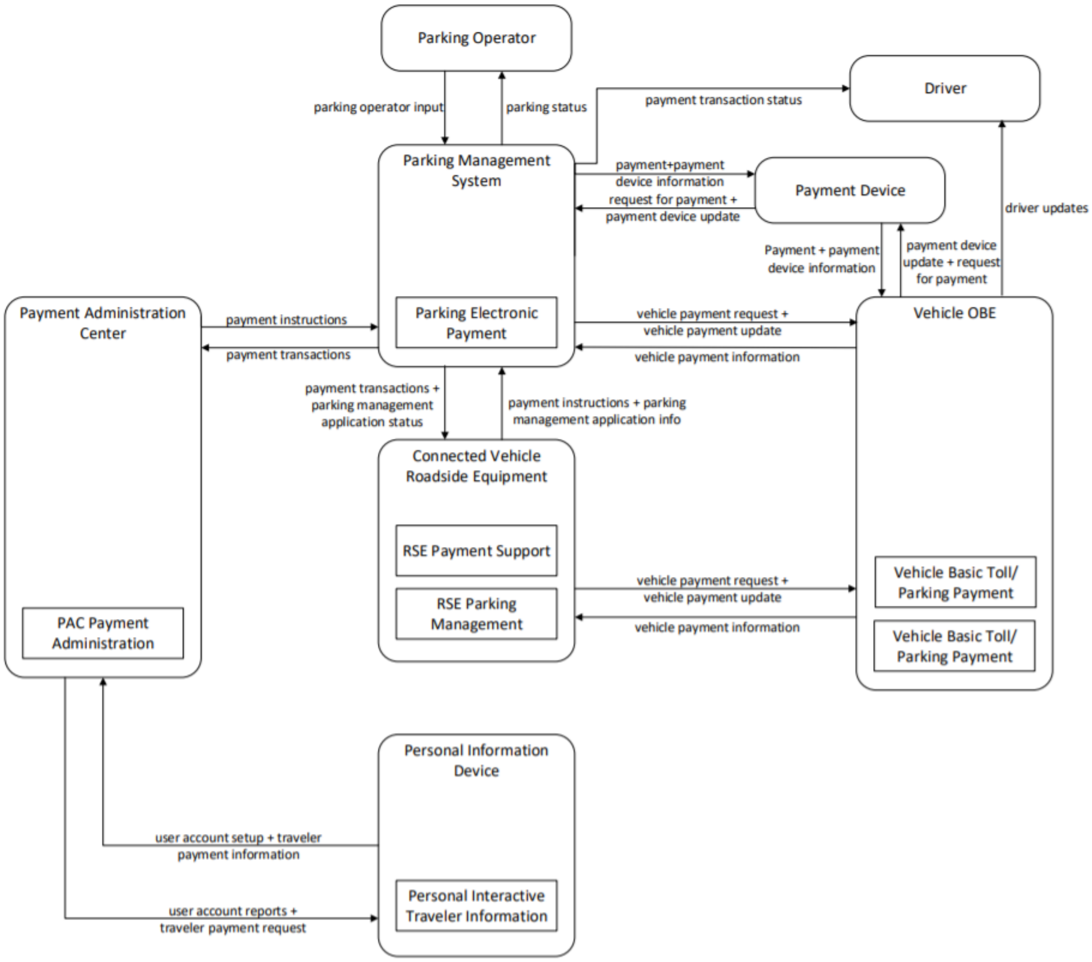

Figure 5: Physical Architecture for the Demand-focused Solution 1

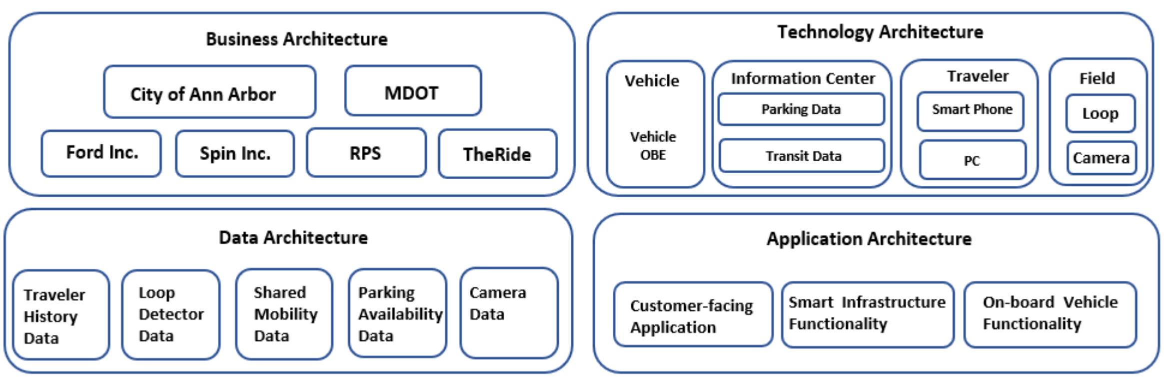

Figure 6: Enterprise Architecture for the Demand-focused Solution 1

- Cost Breakdown and Timeline
  Cost breakdown is shown in Table 8 sand timeline is shown in Table 9.

Table 8: Cost Breakdown of Demand-focused Solution 1

Description	Unit Price	Subtotal
Database and Software for Dynamic Electronic Billing & Pricing	$ 39,300	$ 39,300
Integration for On-Street Parking Data	20,000	$ 20,000
		$ 59,300

Table 9: Timeline of Demand-focused Solution 1

Task	Time Estimation
Stakeholder Meetings	1 month
Public Hearing	3 months
On-street Parking Data Collection	1 month
Dynamic Pricing Decision	1 month
Trial Operation	2 months

2.2.2 Solution 2: Increasing Multi-model Transportation Options

2.2.2.1 Analysis and Description

According to the report *A Survey of Downtown Ann Arbor Commuters and Decision-makers 2018* [4], 42% of commuters in Ann Arbor choose to drive alone, 4% of the commuters use on-street parking meters, and 8% use the non-metered spaces on residential streets. To reduce the demand for on-street parking spaces for commuters, other multi-modal transportation options should be developed and promoted. This survey shows that 35% of commuters who use cars state that they would like to change commuting modes to car-pooling if carpooling program can guarantee a ride home. Additionally, 48% of commuters who use personal vehicles to commute state that the reason preventing them from using public transportation is that buses do not run close enough to where they live or work, and 24% say the reason is that buses take too long. 68% of commuters show the unwillingness to use bikes to work, and the remaining 32% of commuters say the main reason that stops them from using a bike is the bike path conditions. From this survey data we can advocate several plans geared at the demand side of the market to promote using of multi-modal transportation options and reducing the demand for personal vehicles for commuting, thus reducing the demand for on-street parking. We propose to provide the traveller with more transportation choices by:

- **Promoting car-pooling**
  We propose to promote carpooling by providing a shuttle bus system for commuters and priority parking for those who participate in carpooling programs. A frequent and fast shuttle bus system operated from the parking structures around downtown Ann Arbor should be considered by MDOT and TheRide.
- **Improving accessibility and convenience of non-automotive transportation modes**
  We propose to address the curb space shortage problem by shifting demand away from motorized transportation through promoting greener transportation modes, such as scooters. A discounted price for using scooters by vertical parking users should be discussed by the City of Ann Arbor and Spin Inc. to encourage moving people away from on-street parking and increase non-vehicle transportation choices.
- **Promoting information communication among different stakeholders**
  As information is key in making informed decisions, we propose to shift demand away from on-street parking by broadcasting information on parking opportunities to users through an smart phone app. A Digital parking inventory management system should be created to improve the information communication among the Transit Management Center, Alternate Mode Transportation Center, Parking Management System, and users.

2.2.2.2 Con-ops

The architecture of this system is referred to the existing ITS deployments, which is the service package of public transportation, PT14. This service package establishes a two-way communication between multiple transit and traffic agencies to improve service coordination. To upgrade the physical architecture to a three-way communication system, two new functional objects are added, which are'Shuttle Bus Information', 'Vehicle Trip Planning and Route Guidance', and the corresponding physical object is 'Vehicle OBE'.

- Functional Architecture

Physical Object	Functional Object	Description
Traffic Management Center	Traffic Management Center Multi-Modal Coordination	Support center-to-center coordination. Monitor transit operations and provide traffic signal priority for transit vehicles on request.
Transit Management Center	Transit Center Multi-Modal Coordination	Support transit service coordination between transit properties and coordinates with other surface and air transportation modes. Share schedule, trip information, and transit transfer stations information.
Transit Vehicle OBE	Transit Vehicle Schedule Management	Monitor on-board systems, schedule performance and identify corrective actions when a deviation is detected. Provide two-way communication between the transit vehicle operator and center.
Alternate Mode Transportation Center	\	Provide interface through which non-ITS transportation systems (e.g., ferry services, passenger-carrying heavy rail) can exchange data with ITS. Enable people's movement across multi-modes transportation.
Event Promoter System	\	Provide knowledge(date, time, estimated duration, location, etc.) of events that may impact travel on roadways or other modal means.
Parking Management System	\	Provide electronic monitoring and management of parking facilities that allows electronic collection of parking fees. Monitor and control parking lot usage and availability.

Table 10: Functional Architecture for the Demand-focused Solution 2

- Physical Architecture

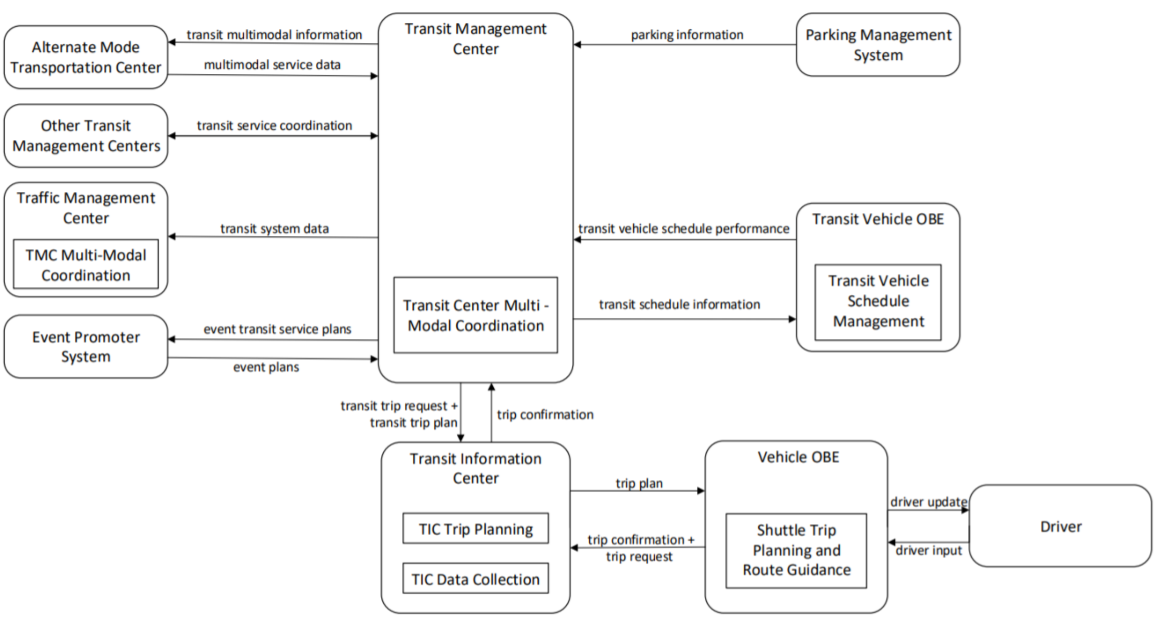

Figure 7: Physical Architecture for Demand-focused Solution 2

- Enterprise Architecture
  The enterprise architecture of the demand-focused solution 2 is presented in Figure 8.
- Cost Breakdown and Timeline
  Cost breakdown is shown in Table 11 sand timeline is shown in Table 12.

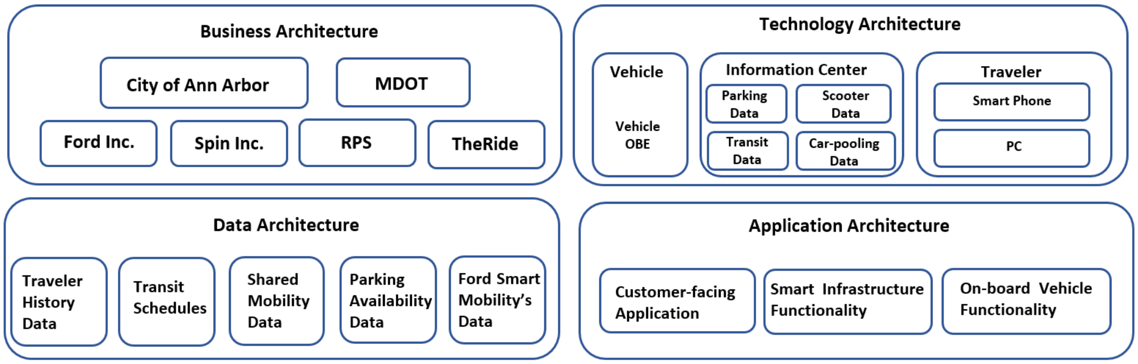

Figure 8: Enterprise Architecture for the Demand-focused Solution 2

Table 11: Cost Breakdown of Demand-focused Solution 2

Description	Unit Price	Subtotal
Shuttle Bus	$ 59,500	$ 59,500
Operation Cost	10,200	$ 10,200
Fuel/Electricity Cost	15,200	$ 15,200
		$ 84,900

Table 12: Timeline of Demand-focused Solution 2

Task	Time Estimation
Stakeholder Meetings	1 month
Public Hearing	3 months
Parking Data Collection	1 month
Bus Schedule Determination	1 month
Trial Operation	2 months

3 Anticipated Outcome

3.1 Benefits

3.1.1 Operational Benefits

The solution requires the improvement of the existing ITS system. It enhances the information communication among different centers and provides more real-time and accurate data for traffic analysis.

3.1.2 Mobility Improvement

The solution balances the parking space occupancy in the downtown and commercial areas, reduces the demand for travelling by car, and reduces the cruising miles by ridesourcing vehicles. This also promotes car-pooling and improve the non-vehicle accessibility, and provides travellers with multi-model transportation choice. As a consequence, it will improve mobility in the region.

3.1.3 Safety Improvement

Proper management of curb space and allocating the curb space according to specific use cases to different sectors will reduce the possibility of accidents. Additionally, the enhancement of ITS system and the video camera will better detect and report the accident.

3.1.4 Environmental Benefits

The estimated environmental benefits include the reduction of fuel consumption and vehicle emissions, both directly through reducing the total miles driven, and indirectly through reducing traffic (since repetitive changes in the acceleration profile is one of the main culprits behind increased fuel consumption). The solution reduces the time for finding parking space and congestion, which can reduce the fuel consumption and emissions. Additionally, it decreases the demand for travelling by car and encourages more energy efficient travel modes such as public transportation, carpooling, and non-motorized modes of transportation.

3.1.5 Economic Benefits

On the one hand, the proposed solution reduces the unnecessary time and fuel wasted on cruising and congestion for the traveler. On the other hand, the solution improves the accessibility and convenience of public transportation and non-vehicle transportation, which is more economic and efficient.

3.1.6 Cooperation

The implementation of the solutions will enhance the collaboration among different agencies and boost the area's transportation industry.

3.2 Impacts and challenges

we anticipate a number of possible challenges for the implementation of the proposed solutions. The application of sensors in smart parking system might require sizable investments, which would require the stakeholders to find resources to cover the cost of the proposed solutions. Dynamic pricing could balance the relationship between supply and demand, but at the same time in might create inequity issues, as part of the population who is of higher socioeconomic status might not be sensitive to marginal changes in parking prices, while other segments of the population may find themselves affected by it. Another set of challenges are introduced due to the necessity of collaboration between the City of Ann Arbor and private ridesourcing or scooter-sharing companies: (1) the city needs to decide how much incentives should be used to ensure a win-win , and find resources to supply the incentives; (2) private stakeholders might not be keen to sharing data, which is one of the critical components that needs to be leveraged for successful deployments.

4 Conclusion

In this document, we proposed a concept-of-operations for a number of demand-focused and supply-focused solutions to improve curb space usage in the downtown area in Ann Arbor. These solutions can be implemented individually or combined, depending on the available resources.

The supply focused solutions aim to make better use of the current existing curb space. In order to do so, we propose to de-conflict the curb space by allocating curb space to different sectors according to time of day and different seasons. Additionally, intelligent and informed parking guidance can be considered to reduce the unnecessary cruising and congestion.

The second type of solutions we propose in this document are demand-focused, aimed at shifting the demand away from on-street parking by providing travelers with alternative transportation alternatives and balancing the occupancy of the curb space. A dynamic pricing method is proposed to guide travelers from high occupancy areas to low occupancy areas in order to make use of the curb space efficiently and save money. Additionally, a multi-modal transportation system solution is proposed to reduce the demand for on-street parking and provide the travellers with more transportation options.

In conclusion, curb space management is an issue that has gained increasing attention, mainly due to new mobility systems that can benefit from curb space usage. This document has proposed a suit of solutions that we believe will help manage the curb space in both short- and long-term.

References

[1] Smart cities collaborative. URL http://smartcities.t4america.org/peer-cities/.

[2] Republic oarking. URL https://www.republicparking.com/.

[3] Downtown Development Authority. Ann arbor downtown parking study. URL https://www.a2gov.org/departments/planning/a2d2/parking/Documents/2007-01_Phase1_Chap3.pdf.

[4] Survey of downtown ann arbor commuters and decision-makers 2018. URL https://www.getdowntown.org/sites/default/files/2019-01/GetDowntown%20Commuter%20and%20Decision-Maker%20Report%202018.pdf.

[5] Dana Afana. Spin scooters to roll in ann arbor as city ditches bird. URL https://www.mlive.com/news/ann-arbor/2019/04/spin-scooters-to-roll-in-ann-arbor-as-city-ditches-bird.html.

[6] About dda. URL https://www.a2dda.org/about-the-dda/.

[7] The shared-use city: Managing the curb. URL https://www.itf-oecd.org/sites/default/files/docs/shared-use-city-managing-curb_3.pdf.

[8] Parking pricing implementation guidelines. URL https://www.vtpi.org/parkpricing.pdf.

[9] Getting the prices right: an evaluation of pricing parking by demand in san francisco. URL http://shoup.bol.ucla.edu/PricingParkingByDemand.pdf.

[10] Xiang Yan, Jonathan Levine, and Robert Marans. The effectiveness of parking policies to reduce parking demand pressure and car use. *Transport Policy*, 73:41 – 50, 2019. ISSN 0967-070X. doi: https://doi.org/10.1016/j.tranpol.2018.10.009. URL http://www.sciencedirect.com/science/article/pii/S0967070X18304402.

A Title of Appendix A

Parking space for commuters is an urgent need. Based on data collected from OnTheMap census data website, as visualized in Figure A.1 and summarized in Table A.2, about 80% of the workforce in Ann Arbor migrates from outside of the city every day, the number of daily commuter counts in year 2017 inside Ann Arbor is 42,464 and 42% of them drive alone to work.

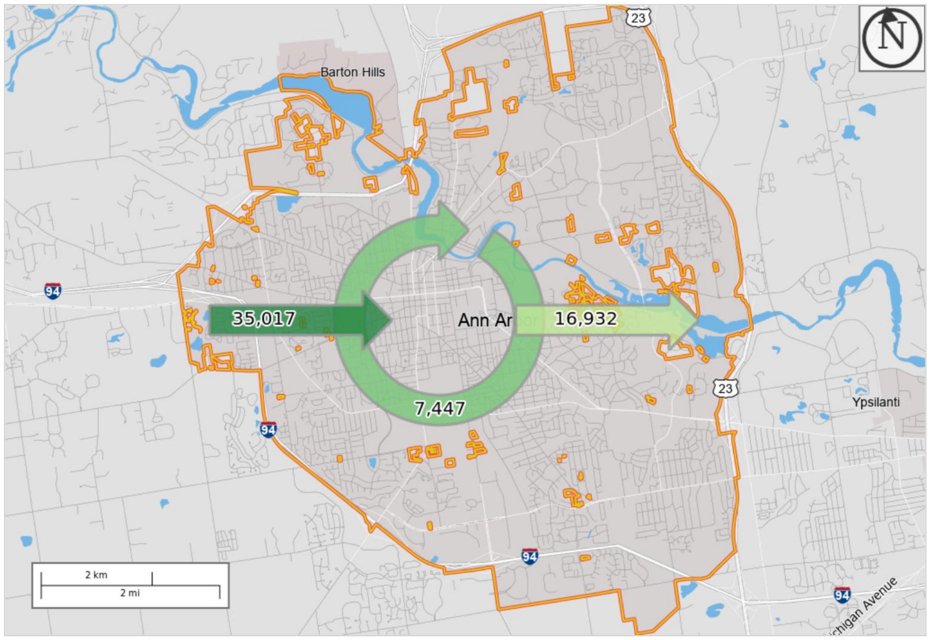

Figure A.1: Annual Inflow & Outflow in Ann Arbor (2017)

Figure A.2: Table: Inflow/Outflow Job Counts (Private Primary Jobs)

Living and Employment (Count & Percentage)		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Employed in the Selection Area	count	46,217	46,235	45,324	47,565	42,193	43,577	50,482	49,073	50,007	42,464
	percentage	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Employed in the Selection Area but Living Outside	count	37,665	37,400	37,487	39,549	34,713	36,121	42,437	40,694	41,955	35,017
	percentage	81%	81%	83%	83%	82%	83%	84%	83%	84%	82%
Living in the Selection Area	count	23,640	24,035	21,846	21,590	22,188	22,175	23,094	24,242	24,641	24,379
	percentage	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Living in the Selection Area but Employed Outside	count	15,088	15,200	14,009	13,574	14,708	14,719	15,049	15,863	16,589	16,932
	percentage	64%	63%	64%	63%	66%	66%	65%	65%	67%	69%